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Leaf litter decomposition and nutrient dynamics in tree plantations at Kurukshetra, Haryana, India

Pooja Arora*

ABSTRACT

Leaf litter production and simultaneous decomposition can account for a significant quantity of the total annual requirement of essential elements for forest plants. This study was carried out to assess the leaf litter decomposition and associated soil nutrient dynamics in the *Tectona grandis* and *Eucalyptus tereticornis* plantation done under the Social Forestry Scheme at Kurukshetra by the Forest Department of Haryana. Nutrient status of fresh, freshly fallen, decomposing, and decomposed leaf samples and the soil samples in terms of C, N, P, K, Ca, and Mg content of both plantations were estimated. A continuous decrease in the nutrient concentration was found in the leaf samples during the decomposition process in both plantations. However, the release of nutrients from *Tectona* leaves was generally found to be more than that of *Eucalyptus* leaf samples for all the nutrients. The decrease was gradual in the case of Carbon, Nitrogen, Phosphorus, and Calcium in both plantations whereas a rapid decline was observed in the case of Potassium and Magnesium. In general, the release of nutrients followed the order $K > Mg > C > P > Ca > N$ in both plantations. The amount of nutrients in soil samples increased from initial to final sampling indicating the continuous accumulation of nutrients that are released from the leaf litter decomposition. However, the increase was gradual, not rapid in both plantations. In general, the soil samples of the *T. grandis* plantation were richer in nutrient concentration than those of the *E. tereticornis* plantation.

Keywords: Litter, decomposition, nutrients, soil carbon, nitrogen

1. INTRODUCTION

Energy flow and nutrient cycling are the two cardinal processes essential for the functioning of an ecosystem. Litterfall is a significant source of essential nutrient flow, organic matter, and energy to the forest soil. Prevailing environmental factors, biomass of standing vegetation, and composition of plant community greatly influence the litterfall production in any ecosystem. Litterfall also provides an essential connection between producers and decomposers. This connection is

supported by the process of litter decomposition which returns energy and nutrients accumulated or fixed by plants to their ultimate sources whether that is soil or atmosphere. The soil microbial communities or their metabolites are responsible to drive and carry out these processes. However, the structure and activity of soil inhabitant microbial communities, and physico-chemical and biological properties of soil are primarily influenced by the chemical properties and composition of the litter fall which in turn is affected by the type of plant community.

Understanding litter production and its decomposition is vital in estimating the fluxes and pools and C and N in different ecosystems. The initial yet fast phase of the decomposition process results in the leaching of dissolved organic matter, which releases C and N in the soil (Klotzbücher et al., 2013). These releases can either be sorbed directly to mineral soil particles or can be used by soil microbes efficiently. The microbes play a crucial role in depositing the products of the biochemical transformation of litter to soil and get them apart or association of silt and clay-size minerals (Grandy and Neff 2008; Cotrufo et al., 2013). Other factors such as weathering, pedoturbation, physical and biochemical breakdown by soil fauna, etc. also help in the addition and accumulation of litter into the soil include (Hattenschwiler et al., 2005). The microbial decomposition of litter released CO₂ adding more than 20% to soil respiration. The other nutrients such as nitrogen, phosphorus, and calcium released through decomposition become available for plant and microbial uptake (Krishna and Mohan, 2017).

Differences between tree species litter decomposition can be attributed to specific substrate quality constituting C:N ratio, lignin content, calcium and magnesium content, etc. which, serve as significant rate-controlling factors (Cornelissen et al., 2006; Hobbie et al., 2006; Cornwell et al., 2008; Gu'sewell and Gessner, 2009; Berg et al., 2010; Paul et al., 2022). The variations in decomposition rates can also be brought by the effect of different tree species on environmental conditions, as tree species have the potential to induce changes in the fertility of soil, soil microclimate, and composition of microbial communities on the soil surface in the forest floor (Aponte et al., 2010; Aponte et al., 2011). All these factors are responsible for influencing the process of decomposition. With these considerations, the study was executed to (i) assess the present nutrient quality status of fresh leaves, freshly fallen leaves, and soil of the study site and (ii) assess the seasonal nutrient status of decomposing leaves and soil after prescribed incubation periods in the field.

2. MATERIALS AND METHODS

The study sites comprising plantations of native species *Tectona grandis* and *Eucalyptus tereticornis* were done under the social forestry scheme by the forest department of Haryana state in the campus of Kurukshetra University, Kurukshetra was selected for sampling (Figure 1). Kurukshetra district of Kurukshetra has an area of 1682.53 sq. Kms and lies between latitude 29°-52' to 30°-12' and longitude 76°-26' to 77°-04' in the North Eastern part of Haryana State. The climate of the study area is scorching in summer (up to 45°C) and severely cold in winter (about 3°C). The yearly rainfall of the district generally varies from 500 to 800mm and is quite unevenly distributed over the area. 81% of annual rainfall is contributed by the southwest monsoon from June to September (CGWB, 2007).

Soil and Plant Sampling

Surface soil samples (0-15cm depth) were selected and collected by composite sampling in each site in marked polythene bags and tightly closed to prevent any air exchange. Some samples were immediately analyzed for moisture content measurement. The other samples were aired for further research. From each plantation, green leaves, freshly fallen leaves, decomposing leaves, and decomposed leaves were also collected for nutrient analysis. The leaves were cleaned, oven dried and ground for further research.

Soil and Plant Analysis

Soil moisture was analyzed using a Moisture meter (IR 60, Denver Instruments). Soil pH and EC were measured in a 1:2 ratio with distilled water. Organic carbon (%) in soil samples and leaf samples was analyzed by dichromate oxidation) method. Total nitrogen in the soil and plant samples was estimated by the Kjeldahl method. Phosphorus content in soil and plant samples was analyzed by the Olsen Method, Calcium and Magnesium Content by EDTA titration, and Potassium by flame photometry.

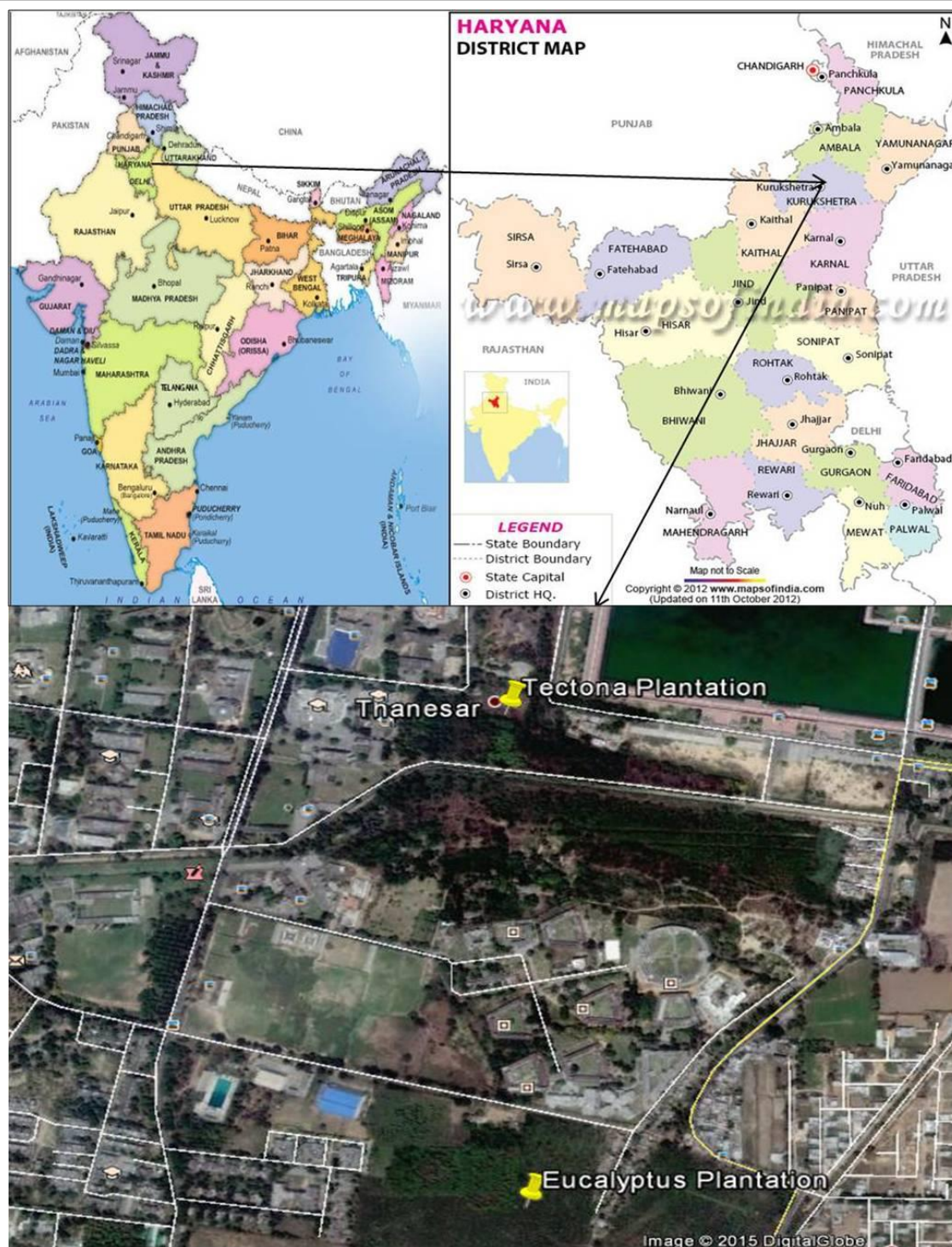


Figure 1 Map view and Google Earth view of the study area

3. RESULTS AND DISCUSSION

Tectona grandis

Leaf Sample Analysis

Leaf samples of *T. grandis* showed a remarkable decrease with increasing stages of the decomposition process. The carbon content of the fresh leaves was observed to be $32 \pm 0.73\%$ while it decreased to $8.4 \pm 0.34\%$ in the decomposed leaves. The total decrease was thus of

about 23.6%. Similarly, the total nitrogen content of the incubated leaves showed a decrease of 4%. The phosphorus content of the fresh leaves was 50.4 ± 1.32 ppm while it was observed to be 35.2 ± 1.24 ppm in decomposed and 29.2 ± 1.25 ppm in decomposed leaves. A decrease of 167.3 ppm was observed in the potassium content of the leaf samples from 189.4 ± 2.45 ppm in fresh leaves to 22.1 ± 2.13 ppm in decomposed leaves. The decline in calcium content was 18.51 ppm and that of magnesium content was 31.85 ppm (Figure 2A-F).

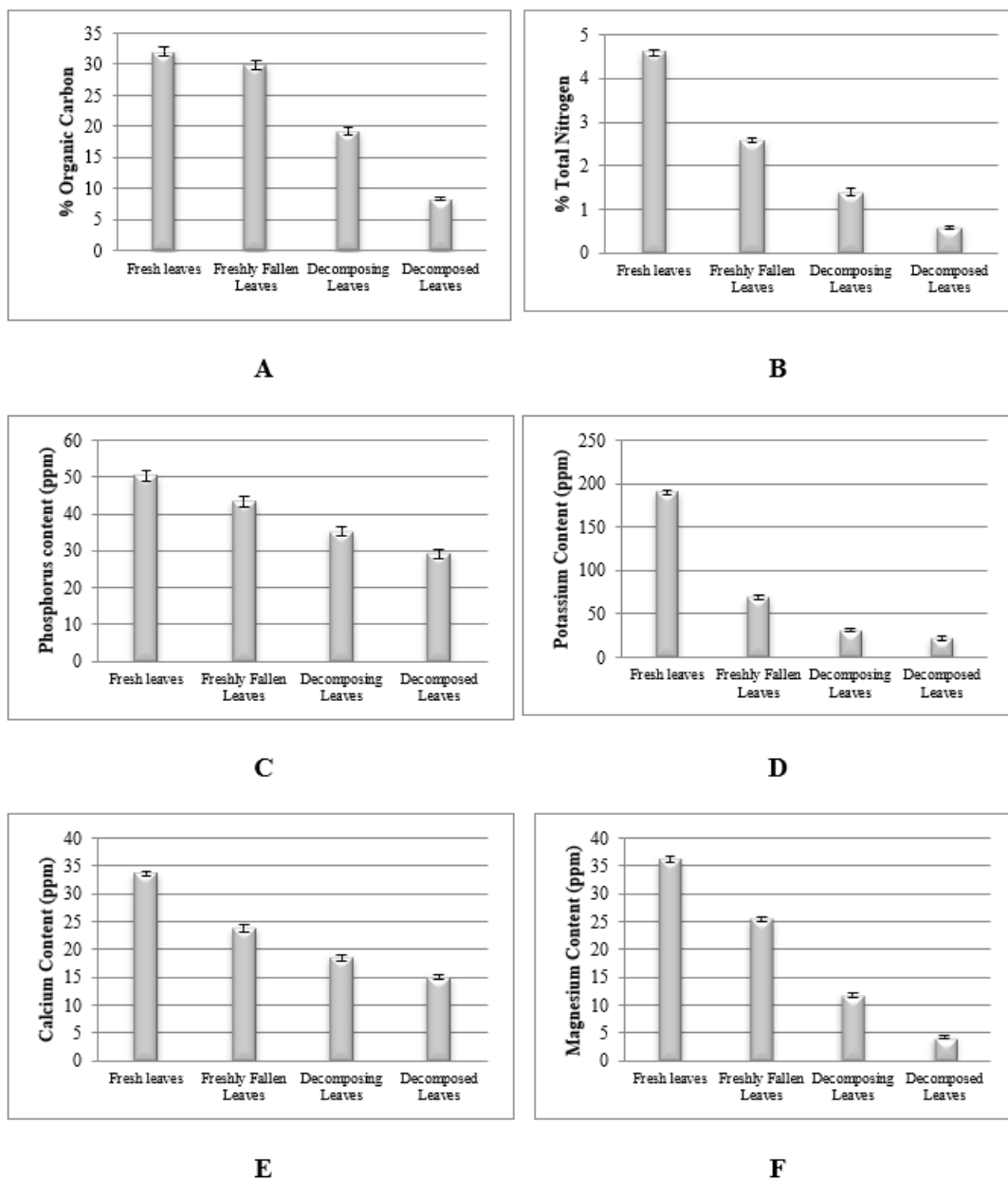


Figure 2 A-F Changes in nutrient status (C, N, P, K, Ca, Mg) of leaf samples of *T. grandis*

Soil Analysis

The moisture content of the soil samples of *T. grandis* plantation ranged from $14.3 \pm 0.03\%$ to $16.79 \pm 0.02\%$, being lowest at the time of third sampling and highest at the time of second sampling of soil samples. The pH of the soil samples was near neutral, ranging from 7.14 ± 0.03 to 7.17 ± 0.01 . The electrical conductivity ranged from $97.6 \pm 0.02 \mu\text{S}$ to $99.3 \pm 0.03 \mu\text{S}$ (Table 1).

Table 1 Physico-chemical parameters of soil samples at different sampling times in *T. grandis*

Physico-chemical Parameters	1st Sampling	2nd Sampling	3rd Sampling
Moisture Content (%)	16.79±0.02	17.6±0.03	14.3±0.03
pH	7.17±0.01	7.15±0.01	7.14±0.01
EC (μS)	99.3±0.14	98.5±0.21	97.6±0.12

An increasing trend was observed in the nutrient concentration in soil samples from the first sampling to the last sampling coinciding with leaf litter decomposition. The percent organic carbon content of the soil samples of *T. grandis* plantation ranged from 0.81±0.01% to 0.88±0.01%. The increase in total nitrogen concentration of the soil sample was from 0.11±0.02% in the first sampling to 0.29±0.01% in the third sampling. The phosphorus concentration ranged from 5.34±0.23ppm to 6.32±0.28ppm and that of potassium concentration ranged from 74.1±0.64ppm to 75±0.72ppm. The calcium content of the soil samples increased from 9.25±0.18ppm to 14.84±0.27ppm. The magnesium content was 1.41±0.07ppm in the first sampling and 3.42±0.09ppm in the third sampling following the release of nutrients from leaf litter via decomposition (Figure 3 A-F).

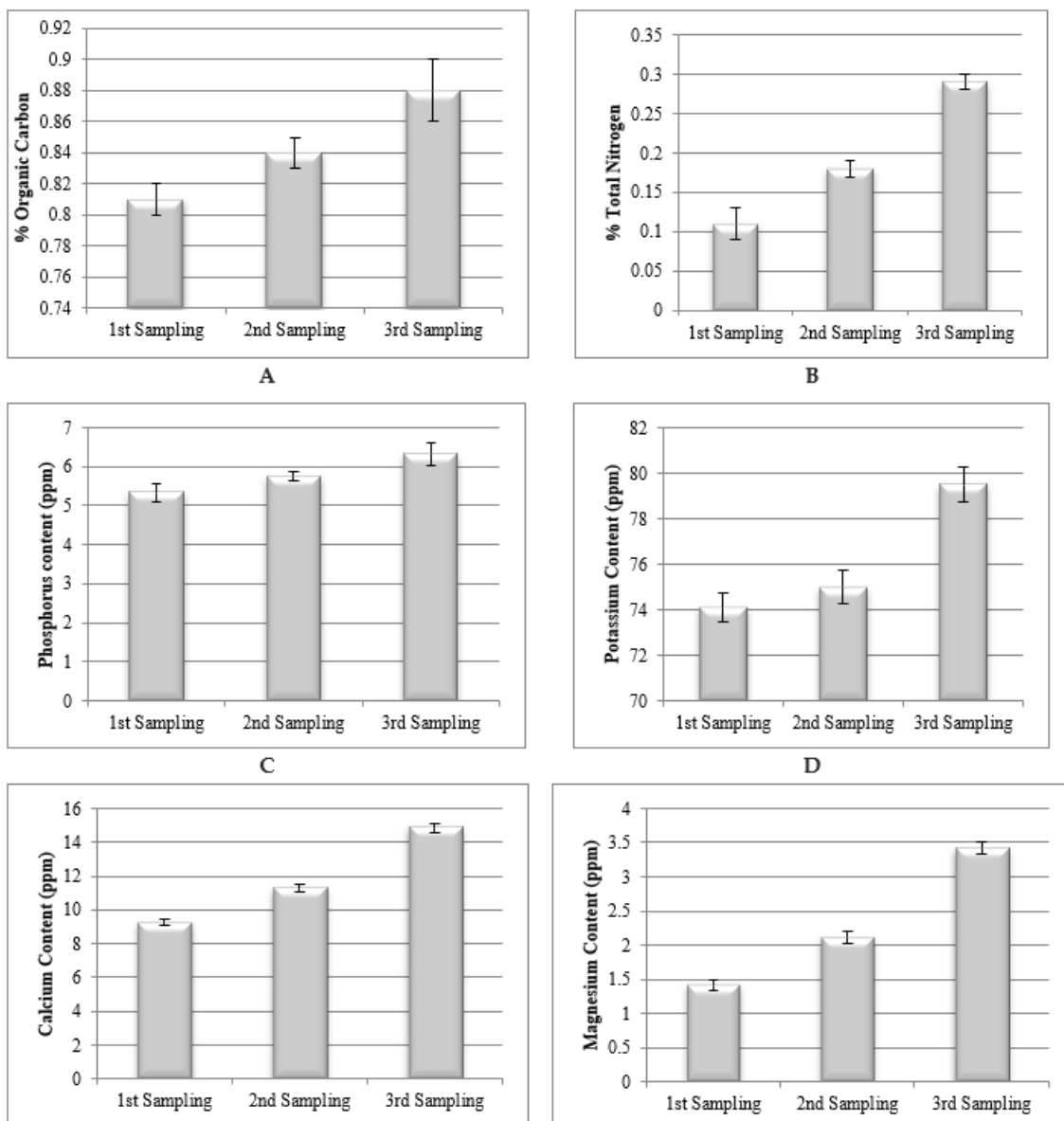
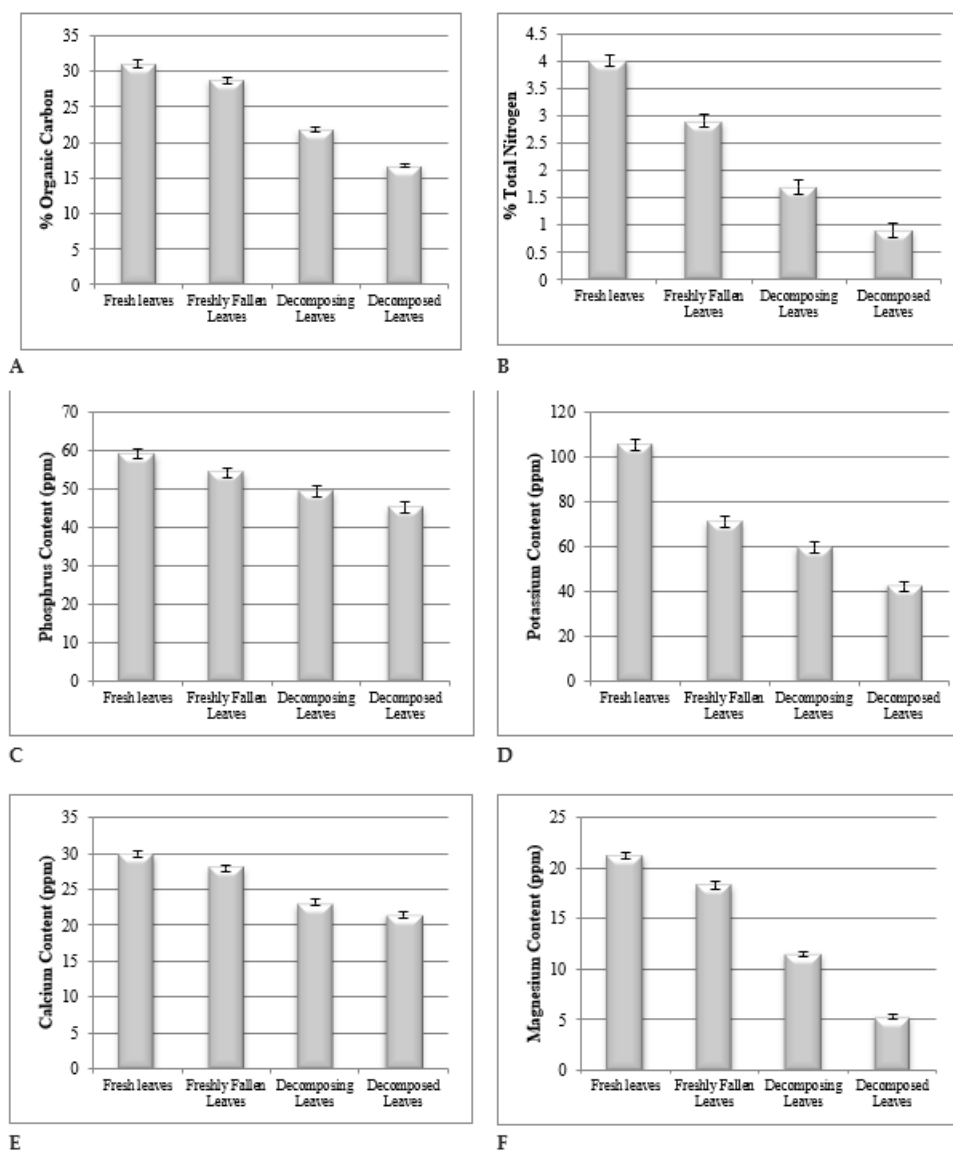


Figure 3 A-F Changes in nutrient status (C, N, P, K, Ca, Mg) of soil samples of *T. grandis****Eucalyptus tereticornis*****Leaf Sample Analysis**

A continuous decrease in the nutrient status of leaf samples with progressing decomposition was also observed in the case of *E. tereticornis*. The carbon content of the leaves decreased from $31\pm0.61\%$ in fresh leaves to $16.7\pm0.26\%$ in decomposed leaves. The total nitrogen content ranged from $4\pm0.11\%$ in fresh leaves to $0.9\pm0.012\%$ in decomposed samples. A decrease of 13.9ppm and 63.1ppm was observed in phosphorus and potassium contents respectively during leaf litter decomposition. The calcium content of the leaf samples decreased from $29.7\pm0.58\text{ppm}$ to $21.3\pm0.55\text{ppm}$ while magnesium content showed a decrease of 15.9ppm (Figure 4 A-F).

**Figure 4 A-F** Changes in nutrient status (C, N, P, K, Ca, Mg) of leaf samples of *E. tereticornis*

Soil Analysis

The moisture content of the soil samples of *E. tereticornis* plantation ranged from 8.9±0.03% to 14.44±0.03% being lowest at the time of third sampling and highest at the time of second sampling of soil samples. The pH of the soil samples was above neutral level ranging from 7.4±0.01 to 7.7±0.01. The electrical conductivity ranged from 105.3±0.21µS to 109±0.14µS (Table 2).

Table 2 Physico-chemical parameters of soil samples at different sampling times in *E. tereticornis*

Physico-chemical Parameters	1st Sampling	2nd Sampling	3rd Sampling
Moisture Content (%)	12.32±0.02	14.44±0.03	8.9±0.03
pH	7.7±0.01	7.6±0.01	7.4±0.01
EC (µS)	109±0.14	105.3±0.21	106.5±0.12

An increasing trend was observed in the nutrient concentration in soil samples from the first sampling to the last sampling coinciding with leaf litter decomposition. The percent organic carbon content of the soil samples of *E. tereticornis* plantation ranged from 0.64±0.02% to 0.71±0.02%. The increase in total nitrogen concentration of the soil sample was from 0.09±0.01% in the first sampling to 0.21±0.02% in the third sampling. The phosphorus concentration ranged from 5.13±0.23ppm to 6.33±0.17ppm and that of potassium ranged from 55.9±0.76ppm to 59.5±0.42ppm. The calcium content of the soil samples increased from 6.75±0.13ppm to 8.87±0.18ppm. The magnesium content was 0.98±0.03ppm in the first sampling and 1.88±0.09ppm in the third sampling following the release of nutrients from leaf litter through the process of decomposition (Figure 5 A-F).

Comparison of leaf litter decomposition among *T. grandis* and *E. tereticornis* plantations

A continuous decrease in the nutrient status of leaf litter was observed in both plantations. However, the release of nutrients from *Tectona* leaves was generally found to be more than that of *Eucalyptus* leaf samples for all the nutrients. The decrease was gradual in the case of Carbon, Nitrogen, Phosphorus, and Calcium in both plantations whereas a rapid decrease was observed in the case of Potassium and Magnesium (Figure 6 A-F).

In general, the release of nutrients followed the order K>Mg>C>P>Ca>N in both plantations. It is understood that the deposition and decomposition of leaf litter are essential channels for the transit of organic matter and nutrients in tropical forests. The decomposition of litterfall contributes to the addition of soil organic matter and the replenishment of nutrients in the soil (Fioretto et al., 2003; Xuluc-Tolosa et al., 2003). Ecosystems are characterized by the interaction between nutrient flux and nutrient storage. The accumulation of organic matter within an ecosystem is regulated by a balance between litter deposition and decomposition (Singh et al., 2004).

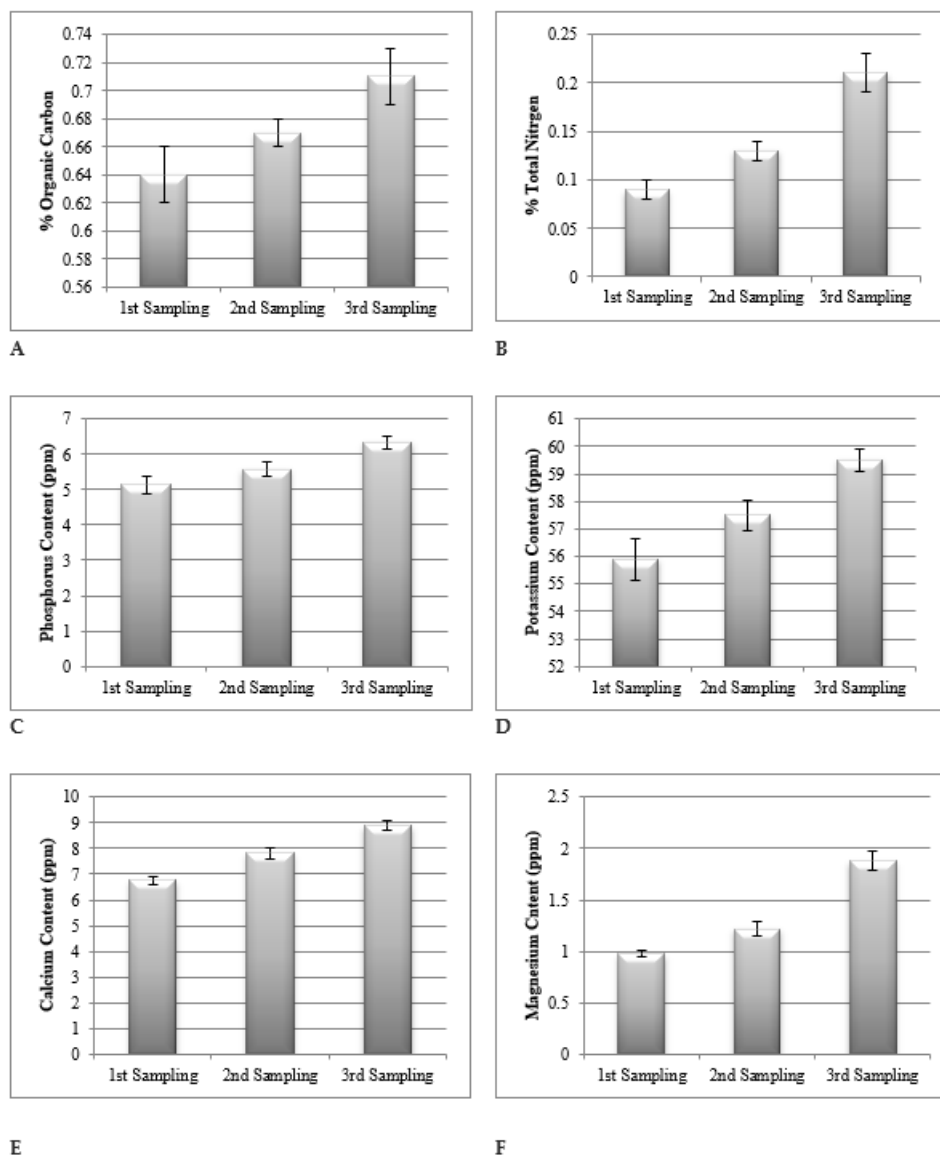


Figure 5 A-F Changes in nutrient status (C, N, P, K, Ca, Mg) of soil samples of *E. tereticornis*

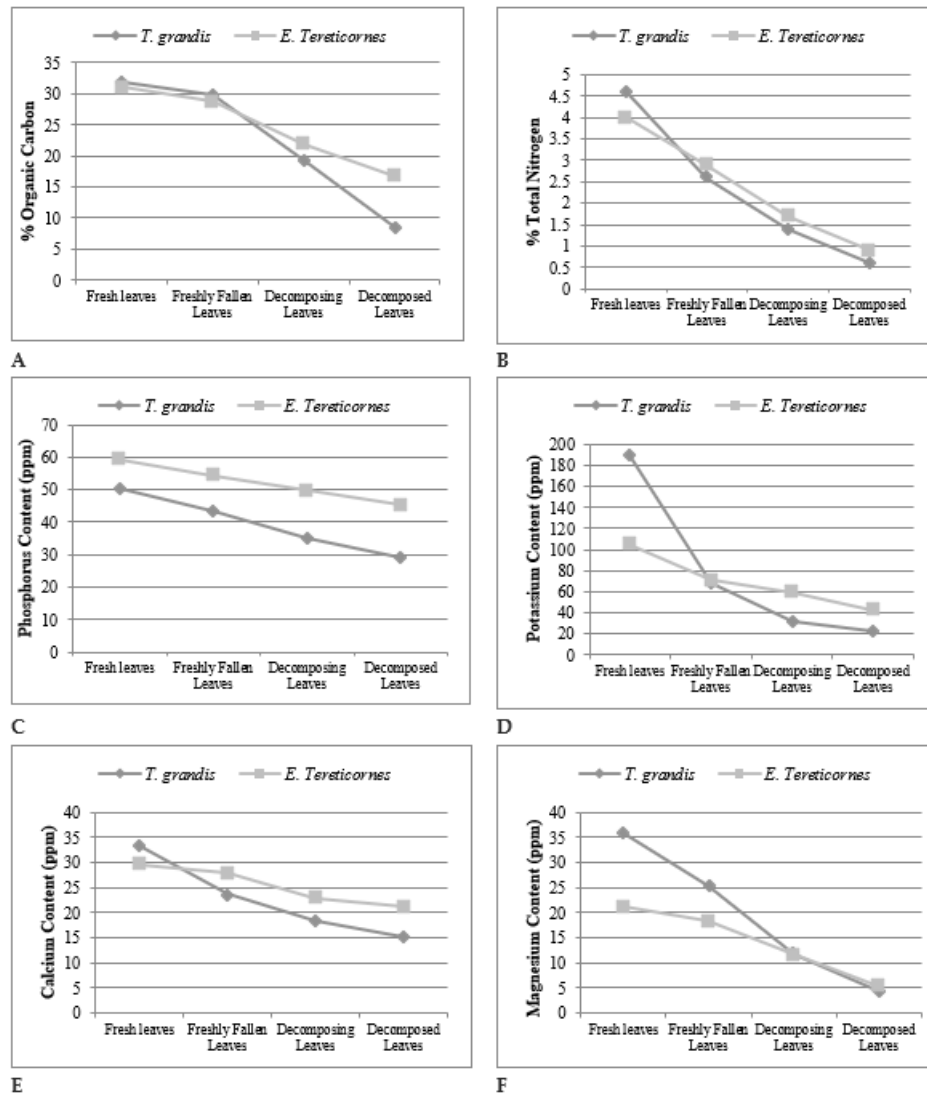


Figure 6 A-F Comparison of leaf litter decomposition regarding nutrient status (C, N, P, K, Ca, Mg) in *T. grandis* and *E. tereticornis* plantations.

4. CONCLUSION

For forest soils to remain fertile, nutrients from decomposing plant litter must be released. Nutrient release patterns vary among species and are dependent on the quality of the litter and seasonal environmental conditions (Kavvadias et al., 2001). In the present study also, it was observed that nutrient concentration in leaf samples of both plantations decreases gradually during the decomposition process releasing nutrients to the soil surface. However, the release of all the nutrients under study was higher in *Tectona* leaves than that of *Eucalyptus* leaf samples for all the nutrients. Carbon, Nitrogen, Phosphorus, and Calcium concentration decreased gradually however the decrease was rapid in the case of Potassium and Magnesium in both plantations. The nutrient concentration in soil samples increased gradually from initial to final sampling representing the continuous accumulation of nutrients released from the leaf litter decomposition as there was no other mode of nutrient addition to the soil as opposed to fertilizer addition in agricultural soils.

In general, the soil samples of the *T. grandis* plantation were richer in nutrient concentration than those of the *E. tereticornis* plantation. When long-term warming happens without moisture restrictions, global climate change is predicted to result in higher decomposition rates. Still, few research studies have also looked at how environmental factors affect the rate of decay in actual field circumstances for a variety of species (Gholz et al., 2000; Santiago et al., 2005; Cornelissen et al., 2007; Zhou et al., 2008; Cusack et al., 2009; Powers et al., 2009; Wieder et al., 2009). Understanding and quantifying the fundamental limits on organic matter decomposition

is essential if we are to understand how tropical rainforests will respond to future climate change in terms of changes to biodiversity and nutrient cycling (Salinas et al., 2010).

Along with enhancing the nutrient quality of soil, litter also serves as a coolant to the soil surface as it reflects the sun's energy and provides shade. It helps in reducing the rate and amount of evaporation maintaining the soil moisture which further supports the soil against periods of low rainfall. Litter cover on the soil surface minimizes the impact of raindrops on soil structure and permits for a slower "percolation" of water into the soil; reduces water erosion and wind erosion; reduces the establishment of weeds by covering the bare ground. Moreover, a thick layer of leaf litter that leaves little to no bare ground will help prevent drought and will hasten pasture recovery when it does rain.

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Author Contribution

The author of the manuscript has done all the work related to planning, fieldwork, sampling, analysis, and manuscript writing of the study.

Ethical Approval

Not applicable.

Informed consent

Not applicable.

Conflicts of interests

The authors declare that there are no conflicts of interests.

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Data and materials availability

All data associated with this study are present in the paper.

REFERENCES

1. Aponte C, García LV, Marañón T, Gardes M. Indirect host effect on ectomycorrhizal fungi: leaf fall and litter quality explain changes in fungal communities on the roots of co-occurring Mediterranean oaks. *Soil Biol Biochem* 2010; 42(5):788–796. doi: 10.1016/j.soilbio.2010.01.014
2. Aponte C, García LV, Pérez-Ramos IM, Gutierrez E, Marañón T. Oak trees and soil interactions in Mediterranean forests: a positive feedback model. *J Veg Sci* 2011; 22(5):856–867. doi: 10.1111/j.1654-1103.2011.01298.x
3. Berg B, Davey M, De-Marco A, Emmett B, Faituri M, Hobbie S, Johansson MB, Liu C, McClaugherty C, Norell L, Rutigliano F, Vesterdal L, Virzo Santo A. Factors influencing limit values for pine needle litter decomposition: a synthesis for boreal and temperate pine forest systems. *Biogeochemistry* 2010; 100:57–73. doi: 10.1007/s10533-009-9404-y
4. CGWB (Central Ground Water Board). Groundwater information Booklet, Kurukshetra District, Haryana. Ministry of Water Resources, Govt. of India, North Western Region, Chandigarh, 2007.
5. Cornelissen JH, Quested HM, van-Logtestijn RS, Pérez-Harguindeguy N, Gwynn-Jones D, Díaz S, Callaghan TV, Press MC, Aerts R. Foliar pH as a new plant trait: can it explain variation in foliar chemistry and carbon cycling processes among subarctic plant species and types? *Oecologia* 2006; 147(2):315–26. doi: 10.1007/s00442-005-0269-z
6. Cornelissen JHC, van-Bodegom PM, Aerts R, Callaghan TV, van Logtestijn RSP, Alatalo J, Stuart Chapin F, Gerdol R,

- Gudmundsson J, Hartley AE, Hik DS, Hofgaard A, Jónsdóttir IS, Karlsson S, Klein JA, Laundre J, Magnusson B, Michelsen A, Molau U, Onipchenko VG, Quested HM, Sandvik SM, Schmidt IK, Shaver GR, Solheim B, Soudzilovskaia NA, Stenström A, Tolvanen A, Totland Ø, Wada N, Welker JM, Zhao X, Team MOL. Global negative vegetation feedback to climate warming responses of leaf litter decomposition rates in cold biomes. *Ecol Lett* 2007; 10(7):619–627. doi: 10.1111/j.1461-0248.2007.01051.x
7. Cornwell WK, Cornelissen JHC, Amatangelo K, Dorrepaal E, Eviner VT, Godoy O, Hobbie SE, Hoorens B, Kurokawa H, Pe'rez-Harguindeguy N, Quested HM, Santiago LS, Wardle DA, Wright IJ, Aerts R, Allison SD, Bodegom PV, Brovkin V, Chatain A, Callaghan TV, Di'az S, Garnier E, Gurvich DE, Kazakou E, Klein JA, Read J, Reich PB, Soudzilovskaia NA, Vaieretti MV, Westoby M. Plant species traits are the predominant control on litter decomposition rates within biomes worldwide. *Ecol Lett* 2008; 11(10):1065–71. doi: 10.1111/j.1461-0248.2008.01219.x
 8. Cotrufo MF, Wallenstein MD, Boot CM, Deneff K, Paul E. The Microbial Efficiency- Matrix Stabilization (MEMS) framework integrates plant litter decomposition with soil organic matter stabilization: do labile plant inputs form stable soil organic matter? *Glob Chang Biol* 2013; 19(4):988–995. doi: 10.1111/gcb.12113
 9. Cusack DF, Chou WW, Yang WH, Harmon ME, Sivver WL, THE LIDET Team. Controls on long-term root and leaf litter decomposition in Neotropical forests. *Glob Chang Biol* 2009; 15(5):1339–1355. doi: 10.1111/j.1365-2486.2008.01781.x
 10. Fioretto A, Papa S, Fuggi A. Litter-fall and litter decomposition in a low Mediterranean shrubland. *Biol Fertil Soils* 2003; 39:37–44. doi: 10.1007/s00374-003-0675-5
 11. Gholz HL, Wedin DA, Smitherma SM, Harmon ME, Parton WJ. Long-term dynamics of pine and hardwood litter in contrasting environments: toward a global model of decomposition. *Glob Chang Biol* 2000; 6(7):751–765. doi: 10.1046/j.1365-2486.2000.00349.x
 12. Grandy AS, Neff JC. Molecular C dynamics downstream: The biochemical decomposition sequence and its impact on soil organic matter structure and function. *Sci Total Environ* 2008; 404(2-3):297–307. doi: 10.1016/j.scitotenv.2007.11.013
 13. Gu'sewell S, Gessner MO. N:P ratios influence litter decomposition and colonization by fungi and bacteria in microcosms. *Funct Ecol* 2009; 23(1):211–19. doi: 10.1111/j.1365-2435.2008.01478.x
 14. Hattenschwiler S, Tiunov AV, Scheu S. Biodiversity and litter decomposition in terrestrial ecosystems. *Annu Rev Ecol Evol Syst* 2005; 36:191–218. doi: 10.1146/annurev.ecolsys.36.112904.151932
 15. Hobbie SE, Reich PB, Oleksyn J, Ogdahl M, Zytowskiak R, Hale C, Karolewski P. Tree species effects on decomposition and forest floor dynamics in a common garden. *Ecol* 2006; 87(9):2288–97. doi: 10.1890/0012-9658(2006)87[2288:TSEODA]2.0.CO;2
 16. Kavvadias VA, Alifragis D, Tsiontsis A, Brofas G, Stamatelos G. Litterfall, litter accumulation, and litter decomposition rates in four forest ecosystems in Northern Greece. *For Ecol Manag* 2001; 144(1-3):113–127. doi: 10.1016/S0378-1127(00)00365-0
 17. Klotzbücher T, Kaiser K, Filley T, Kalbitz K. Processes controlling the production of aromatic water-soluble organic matter during litter decomposition. *Soil Biol Biochem* 2013; 67:133–139. doi: 10.1016/j.soilbio.2013.08.003
 18. Krishna MP, Mohan M. Litter decomposition in forest ecosystems: a review. *Energ Ecol Environ* 2017; 2:236–249. doi: 10.1007/s40974-017-0064-9
 19. Paul OJ, Ojomah FO. Effects of land uses on soil organic carbon stock and soil total nitrogen stock in Anyigba, Kogi State, Nigeria. *Discovery* 2022; 58(319):800–806
 20. Powers JS, Montgomery RA, Adair EC, Brearley FQ, DeWalt SJ, Castanho CT, Chave J, Deinert E, Ganzhorn JU, Gilbert ME, González-Iturbe JA, Bunyavejchewin S, Grau HR, Harms KE, Hiremath A, Iriarte-Vivar S, Manzane E, de-Oliveira AA, Poorter L, Ramanamanjato J-B, Salk C, Varela A, Weiblen GD, Lerdau MT. Decomposition in tropical forests: a pan-tropical study of the effects of litter type, litter placement and mesofaunal exclusion across a precipitation gradient. *J Ecol* 2009; 97(4):801–811. doi: 10.1111/j.1365-2745.2009.01515.x
 21. Salinas N, Malhi Y, Meir P, Silman M, Cuesta RR, Huaman J, Salinas D, Huaman V, Gibaja A, Mamani M, Farfan F. The sensitivity of tropical leaf litter decomposition to temperature: results from a large-scale leaf translocation experiment along an elevation gradient in Peruvian forests. *New Phytol* 2010; 189(4):967–977. doi: 10.1111/j.1469-8137.2010.03521.x
 22. Santiago LS, Schuur EAG, Silvera K. Nutrient cycling, and plant–soil feedbacks along a precipitation gradient in lowland Panama. *J Trop Ecol* 2005; 21(4):461–470. doi: 10.1017/S0266467405002464
 23. Singh RK, Dutta RK, Agrawal M. Litter decomposition and nutrient release about atmospheric deposition of S and N in a dry tropical region. *Pedobiologia* 2004; 48(4):305–311. doi: 10.1016/j.pedobi.2004.03.003

24. Wieder WR, Cleveland CC, Townsend AR. Controls over leaf litter decomposition in wet tropical forests. *Ecol* 2009; 90(12):333–3341. doi: 10.1890/08-2294.1
25. Xuluc-Tolosa FJ, Vester HFM, Ramirez-Marcial N, Castellanos-Albores J, Lawrence D. Leaf litter decomposition of tree species in three successional phases of tropical dry secondary forest in Campeche, Mexico. *For Ecol Manag* 2003; 174(1-3):401-412. doi: 10.1016/S0378-1127(02)00059-2
26. Zhou GY, Sun G, Wang X, Zhou CY, McNulty SG, Vose JM, Amatya DM. Estimating Forest ecosystem evapotranspiration at multiple temporal scales with a dimension analysis approach. *JAWRA* 2008; 44(1):208–221. doi: 10.1111/j.1752-1688.2007.00148.x